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Original Communication

Estimation of stature from dimensions of hands and feet in a North Indian population

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Abstract

In medico-legal autopsies, establishing personal identity of the victims is often required. Estimation of stature from extremities and their parts plays an important role in identifying the dead in forensic examinations. The study examines the relationship between stature and dimensions of hands and feet among Rajputs of Himachal Pradesh – a North Indian endogamous group. The purpose for understanding these examinations was the paucity in the literature of studies that allow the reconstruction of stature from various dimensions of hands and feet amongst Rajputs. Hand length, hand breadth, foot length and foot breadth of 246 subjects comprising 123 males and 123 females ranging in age from 17 to 20 years were taken independently on left and right side of each individual. Statistical analyses indicated that the bilateral variation was insignificant for all the measurements except hand breadth in both the sexes ($P < 0.01$). Sex differences were found to be highly significant for all the measurements ($P < 0.01$). Linear and multiple regression equations for stature estimation were calculated using the above mentioned variables. The correlation coefficients between stature and all the measurements of hands and feet were found to be positive and statistically significant. The highest correlation coefficient between stature and foot length and lowest SEE (standard error of estimate) indicate that the foot length provides highest reliability and accuracy in estimating stature of an unknown individual. The regression equations were checked for their accuracy by comparing the estimated stature and actual stature.

Keywords: Forensic medicine; Forensic anthropology; Stature estimation; Anthropometry; Hands and feet; Rajputs

1. Introduction

Stature provides insight into various features of a population including nutrition, health and genetics. Stature is considered as one of the parameters for personal identification and one of the 'big fours' of forensic anthropology. The stature of an individual is an inherent characteristic; its estimate is considered to be an important assessment in the identification of unknown human remains.

Adult height may be attained anywhere from the early teens to early twenties, though it is most commonly reached during mid-teens for females and the late-teens for males. For better accuracy, stature estimation may be attempted only after the attainment of maturity.

There is an established relationship between stature and various body parts like head, trunk, upper and lower extremities. This allows a forensic scientist to estimate stature from different parts of the body. With the increasing frequency of mass disasters, homicides, air plane crashes, train and road accidents etc., there is always need for such studies which help in identifying the deceased from fragmentary and dismembered human remains. In such a situation, measurements of hands and feet provide good approximation about the height of a person.

Some of the authors have successfully tried to estimate stature from percutaneous body measurements,[1–13] some from the isolated long and other bones[14–22] and some focused their attention on the estimation of stature using radiographic material.[23–26]

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The purpose of the present study is to analyze the anthropometric relationship between dimensions of hands and feet with stature and to devise regression formulae to estimate stature from these dimensions.

2. Materials and methods

The present study consists of a cross-sectional sample of 246 Rajputs (123 males and 123 females), ranging in age from 17 to 20 years. Rajputs are one of the major endogamous caste groups of North India, a large number of them living in Himachal Pradesh. The study was conducted in Theog tehsil of district Shimla in the state of Himachal Pradesh. Theog is geographically located at latitude (31.12°) 31° 7′ 12″ North of the Equator and longitude (77.35°) 77° 20′ 59″ East of the Prime Meridian on the Map of the world. The town of Theog is situated at an altitude of 1964 m above mean sea level on Chandigarh–Shimla–Tibet National Highway. The temperature varies considerably in the region while minimum temperature goes down much below 0 °C during the winter months and experiences heavy snow fall; the maximum temperature exceeds even 25 °C during summer months.

The sample for the present study was drawn from Government Senior Secondary School and Government Degree College, Theog. Four anthropometric measurements viz. hand length, hand breadth, foot length and foot breadth were taken independently on the left and right side of each individual. Besides these, stature and weight of each subject were also recorded. Only right handed subjects were included in the present study. All the measurements were taken in a well lighted room. Before taking the measurements, each subject was asked to remove the shoes. The measurements were taken by one observer (AS) in order to avoid inter-observer error. The measurements were taken using standard anthropometric instruments in centimeters to the nearest millimeter according to the techniques described by Vallois.[27] The subjects included in the study were healthy and free from any apparent symptomatic deformity. The study was conducted during the month of September, 2004. Some general information pertaining to economic status, family size, caste, education, occupation etc. was also recorded.

The data were subjected to statistical analysis using statistical package for social sciences (SPSS) and regression formulae were calculated for various combinations to reach the best estimate possible.

2.1. Landmarks and techniques involved in taking anthropometric measurements

2.1.1. Height-vertex (stature)

It is the vertical distance between the point vertex and the floor.

Vertex: It is the highest point on the head when head is held in F.H. (Frankfurt Horizontal) plane.

Instrument: Anthropometer.

Technique: The subject is made to stand in an erect posture and measurement is taken without any wear on head and foot. The subject should stand up against the wall, feet axis parallel or slightly divergent with head balanced on neck in F.H. plane. Hands should hang down. If a wall is not available the subject should stand in an erect posture on a leveled floor. Held the anthropometer vertically in front of the subject exactly in mid-sagittal plane and by the right hand, movement of cross rod is controlled. No pressure should be exerted since this is a contact measurement.

2.1.2. Hand length

It is projected distance between the points inter-stylion and the tip of the third finger.

Inter-stylion: It is the middle point of the line connecting the point stylion radiale (the most distal point on the styloid process of radius) and stylion ulnare (the most distal point on the styloid process of ulna).

Instrument: Anthropometric rod compass.

Technique: The subject is asked to stand erect. The hand, being pendent along the body, is held with the left hand, which presses on the fingers to keep them fully extended. The measuring apparatus, held in the right hand is placed along the radial border at the hand, its stem being strictly parallel to the axis of the hand (the axis of the medius extending the axis of the fore-arm). The end of the upper branch is applied to the inter-stylion point and the end of the lower branch to the tip of the third finger and reading is recorded.

2.1.3. Hand breadth

It is the distance between the most prominent point, outside of the lower epiphyses of the 2nd metacarpal (metacarpal radiale) to the most prominent inside point of the lower epiphyses (metacarpal ulnare) of the 5th metacarpal.

Metacarpal-radiale: It is the point most medially projected on the head of the 2nd metacarpal when the hand is stretched.

Metacarpal-ulnare: It is the point projecting most laterally from the head of the 5th metacarpal.

Instrument: Sliding caliper.

Technique: The measurement is taken over the dorsum of the hand in full extension. It is easy to locate the points by palpation of the landmarks corresponding to the heads of the metacarpal which should not be confused with the upper epiphyses of the finger joints. This ‘breadth’ is somewhat oblique with regards to the axis of the hand.

2.1.4. Foot length

It is the distance from the most prominent part of the heel backward to the most distal part of the longest toe (2nd or 1st).

Acropodian: It is the most forwardly projecting point on the head of the 1st or 2nd toe which ever is larger when the subject stands erect.

Pternion: It is the most backwardly projecting point on the heel when the subject is standing upright with equal pressure on both the feet.

Instrument: Sliding caliper or anthropometric rod compass.

Technique: The measurement should be made on the standing subject, his right leg being slightly bent and drawn backward so that the body-rests mainly on the left foot, which one is to be measured. The caliper is horizontally placed along the inner border of the foot.

2.1.5. Foot breadth

It is the distance between the points of the anterior epiphyses (distal) of the 1st metatarsal, the most prominent of the inner side of the foot (metatarsal-tibiale), and the joint of the anterior epiphyses of the 5th metatarsal, the most prominent of the outer side (metatarsal-fibulare).

Metatarsal-tibiale: It is the most medially projecting point on the head of the 1st metatarsal bone when the subject stands erect.

Metatarsal-fibulare: It is the point most laterally projecting on the head of the 5th metatarsal bone, when the subject stands erect.

Instrument: Sliding caliper.

Technique: The measurement which is taken in the dorsal region of the foot 'loaded' as in the preceding measurement is oblique with regard to length.

3. Results and discussion

Table 1 shows descriptive statistics for stature and measurements of hands and feet in both the sexes. Mean value, standard deviation, standard error of mean and range in stature, hand length, hand breadth, foot length and foot breadth on both bilateral sides are presented. The values of all the measurements in case of males are higher than in females and these sex differences are statistically significant ($p < 0.01$).

Table 2 depicts the bilateral differences (differences in the means) in measurements of hands and feet in both the sexes. It is observed that the hand breadth exhibits statistically significant bilateral differences in both males and females ($p < 0.01$). No statistically significant bilateral differences are found in the measurements of hand length, foot length and foot breadth, however, the right side presents higher mean values.

Table 3 illustrates the correlation coefficients between stature and dimensions of hands and feet on left and right sides in both the sexes. All the measurements exhibit statistically significant correlation coefficients with stature ($p < 0.01$). Correlation coefficients of the length measurements are higher than that of breadth measurements in both the sexes. It is also observed that in males, the highest correlation is exhibited by left foot length ($r = 0.741$) and the lowest by right foot breadth ($r = 0.315$). Similarly, in

Table 1
Descriptive statistics for stature and measurements (cm) of hands and feet in males and females

Variable	Males ($n = 123$)					Females ($n = 123$)					t-value[a] (sex difference)
	Mean	SD	SEM	Min.	Max.	Mean	SD	SEM	Min.	Max.	
Stature	168.24	6.50	0.59	147.6	183.6	155.72	5.18	0.47	140.7	169.5	16.712
Left hand length	18.21	0.91	0.08	15.9	20.8	16.80	0.83	0.08	15.1	19.2	12.780
Right hand length	18.24	0.90	0.08	16.0	20.9	16.83	0.80	0.07	15.2	19.0	12.863
Left hand breadth	8.09	0.43	0.04	7.1	9.8	7.29	0.43	0.39	6.1	8.5	17.731
Right hand breadth	8.23	0.39	0.04	7.3	9.6	7.40	0.42	0.04	6.4	9.0	15.992
Left foot length	24.70	1.21	0.11	21.7	28.6	22.60	1.06	0.10	20.4	24.9	14.495
Right foot length	24.72	1.19	0.12	21.8	28.0	22.65	1.06	0.10	20.4	25.4	11.469
Left foot breadth	9.50	0.61	0.06	8.0	10.8	8.53	0.68	0.06	7.2	10.0	11.692
Right foot breadth	9.52	0.61	0.55	8.0	10.9	8.56	0.68	0.06	7.2	10.0	11.688

[a] Significant at 0.1% level.

Table 2
Bilateral differences in measurements (cm) of hands and feet in males and females

Variable	Males ($n = 123$)			Females ($n = 123$)		
	Mean difference (right–left)	SD	t-value	Mean difference (right–left)	SD	t-value
Hand length	0.026	0.19	1.52	0.38	0.24	1.76
Hand breadth	0.136	0.24	6.25[a]	0.11	0.20	5.90[a]
Foot length	0.016	0.26	0.69	0.042	0.36	1.30
Foot breadth	0.022	0.17	1.45	0.024	0.14	1.85

[a] Significant at 0.1% level.

Table 3
Correlation between stature and anthropometric measurements

Variable	Value of r[a]	
	Male	Female
Left hand length	0.609	0.677
Right hand length	0.599	0.686
Left hand breadth	0.537	0.403
Right hand breadth	0.514	0.503
Left foot length	0.741	0.734
Right foot length	0.732	0.739
Left foot breadth	0.324	0.323
Right foot breadth	0.315	0.294

[a] Significant at 0.1% level.

the females, right foot length ($r = 0.739$) and right foot breadth ($r = 0.294$) exhibit the highest and lowest correlation coefficients respectively.

Table 4 lists the regression equations for estimation of stature from measurements of hands and feet in both the sexes. Worldwide, the regression formulae are accepted as of utmost importance in determination of stature from various anthropometric dimensions. Regression equations have been computed separately, for each sex, each side and for each measurement of the hand and foot. A computer analysis of the data enabled the calculation of regression coefficients 'a' and 'b', where 'a' is the regression coefficient of the dependent variable i.e. stature and 'b' is the regression coefficient of the independent variable i.e. hand length, hand breadth, foot length or foot breadth. Hence, stature $= a + bx$; where $x = a$ measurement of hand or foot. The table also exhibits standard error of estimate (SEE) along with linear regression equations for hand length, hand breadth, foot length and foot breadth on bilateral sides in both sexes. The SEE predicts the deviations of estimated stature from the actual stature. It ranges between ±4.38 and ±6.19 for males and between ±3.50 and ±4.97 for females. A low value indicates greater reliability in the estimated stature. Foot length exhibits lower values on left and right sides in both the sexes indicating that the foot length gives better reliability for prediction of stature.

Since the bilateral differences were not significant for hand length, foot length and foot breadth; the combined regression formulae for stature estimation are

Males	Females
$S = 88.243 + 4.39$ HL	$S = 81.314 + 4.42$ HL
$S = 68.085 + 4.054$ FL	$S = 71.941 + 3.703$ FL
$S = 135.240 + 3.47$ FB	$S = 135.419 + 2.37$ FB

Table 5 presents multiple regression equations for the estimation of stature from different combinations of the dimensions of left hands and feet in both the sexes. It is observed that the multiple regression equations reveal lower values of SEE (i.e. ±2.10 in males and ±2.06 in females) than the values given by linear regression equations. Interpretation suggested that the multiple regression equations are better indicators of stature estimation.

Table 6 presents a comparison of actual stature and stature estimated from measurements of hands and feet using linear regression equations. Minimum, maximum and mean values of the measurements were substituted in their respective regression equation and the estimated stature was calculated. In both the sexes, minimum and maximum estimated stature shows greater variation with respect to the actual minimum and maximum stature. However, the mean value estimates (mean estimated stature) are close to actual stature. This is due to the fact that regression equations are calculated from measures of central tendency.

The results of the present study show that the dimensions of hands and feet can successfully be used for estimation of stature by law enforcement agencies and forensic scientists. The only precaution which must be taken into consideration is that these formulae are applicable to the

Table 4
Linear regression equations for estimation of stature (cm) from measurements of hands and feet

Males		Females	
Regression equations	±SEE	Regression equations	±SEE
$S = 89.63 + 4.31$ RHL	±5.22	$S = 81.22 + 4.43$ RHL	±3.78
$S = 88.63 + 4.37$ LHL	±5.17	$S = 84.54 + 4.24$ LHL	±3.82
$S = 98.23 + 8.51$ RHB	±5.60	$S = 110.39 + 6.13$ RHB	±4.50
$S = 102.11 + 8.17$ LHB	±5.50	$S = 120.41 + 4.83$LHB	±4.76
$S = 69.028 + 4.01$ RFL	±4.44	$S = 73.88 + 3.61$ RFL	±3.50
$S = 69.544 + 3.99$ LFL	±4.38	$S = 74.82 + 3.58$ LFL	±3.53
$S = 136.39 + 3.35$ RFB	±6.19	$S = 136.47 + 2.25$ RFB	±4.97
$S = 135.33 + 3.46$ LFB	±6.17	$S = 134.83 + 2.45$ LFB	±4.92

S = stature, RHL = right hand length, LHL = left hand length, RHB = right hand breadth, LHB = left hand breadth, RFL = right foot length, LFL = left foot length, RFB = right foot breadth, LFB = left foot breadth.

Table 5
Multiple regression equations for estimation of stature (cm) from measurements on left side

Males		Females	
Multiple regression equations	±SEE	Multiple regression equations	±SEE
$S = 83.39 + 3.03$ HL $+ 1.88$ HB -1.73 FL $+ 5.91$ FB	±2.10	$S = 84.96 + 3.53$ HL $+ 2.17$ HB -1.59 FL $+ 3.57$ FB	±2.06
$S = 109.04 + 2.19$ HL $+ 2.31$ HB	±3.25	$S = 94.79 + 2.91$ HL $+ 1.89$ HB	±3.16
$S = 99.59 + 1.51$ FL $+ 3.29$ FB	±3.02	$S = 79.36 = 2.60$ FL $+ 2.11$ FB	±2.98

S = stature, HL = hand length, HB = hand breadth, FL = foot length, FB = foot breadth.

Table 6
Comparison of actual stature and stature estimated (cm) from measurements of hands and feet

Estimated stature using regression equations for	Males			Females		
	Minimum estimated stature	Maximum estimated stature	Mean estimated stature	Minimum estimated stature	Maximum estimated stature	Mean estimated stature
Hand length	158.04	179.99	168.27	148.13	166.27	155.74
Right hand breadth	160.32	179.89	168.23	149.61	164.32	155.72
Left hand breadth	160.11	182.16	168.23	149.96	161.58	155.71
Foot length	156.04	184.0	168.23	147.48	166.0	155.72
Foot breadth	163.0	172.72	168.23	152.52	159.17	155.71
Actual stature	147.6 (minimum)	183.6 (maximum)	168.24 (mean)	140.70 (minimum)	169.50 (maximum)	155.72 (mean)

population from which the data have been collected due to inherent population variations in these dimensions which may be attributed to genetic and environmental factors like climate, nutrition etc.[4,28,29]

In the present study, males show higher mean values in each anthropometric dimension than among females. These statistically significant differences may be attributed to the early maturity of girls than boys; consequently, the boys have two more years of physical growth.

As far as the bilateral asymmetry is concerned, only the hand breadth in both the sexes showed statistically significant asymmetry and the right side shows preponderance over the left side in this right handed sample. The results are in concordance with the study conducted by Lamb[30] who stated that the width of the hand is influenced by preponderance and attributed this to the effect of muscular contraction acting on bone. Other measurements i.e. hand length, foot length and foot breadth do not show any significant asymmetry. Similar results were obtained by Schell et al.[31] and Cohen[32] for hand length and Jasuja et al.[33] for foot length, however, Krishan and Sharma[34] in their study showed significant asymmetry in hand length among the Punjabi adolescents.

Foot length in both the sexes depicts higher correlation coefficients with stature than that of any other measurement. Thus, foot length is the best parameter for estimating stature. This is also supported by lower SEE in case of foot length in both the sexes. Foot measurements exhibit higher correlations with stature than the hand measurements. This may be attributed to the fact that foot is anatomically involved in the stature of a person. It is also noticed that female Rajputs exhibit a low SEE (±2.06–3.16 cm.) and a relatively higher correlation coefficient between stature and all the dimensions of hands and feet than those observed in their male counterparts (SEE ±2.10–3.25 cm.). It suggests that the accuracy in predicted stature would be greater among females than that of males.

4. Conclusion

It is concluded that the dimensions of hands and feet can provide good reliability in estimation of stature in forensic examinations. Foot length gives better prediction of stature than that of foot breadth, hand length and hand breadth in both the sexes. Stature prediction is more accurate and reliable in case of female Rajputs than in male Rajputs. It is also observed that a single dimension of hand or foot can estimate stature of an unknown person with a great accuracy and a small standard error of estimate i.e. about 2–6 cm. Foot dimensions have greater association with stature than hand dimensions.

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